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Investigation of Improved Airborne Antenna Techniques for Combat Surveillance

Fifth Quarterly Progress Report
1 June 1963 to 31 August 1963

Home Office, St. Petersburg, Florida

ELECTRONIC COMMUNICATIONS, INC.

RESEARCH DIVISION ■ 1830 YORK ROAD ■ TIMONIUM, MARYLAND

Investigation of Improved Airborne Antenna

Techniques for Combat Surveillance

Fifth Quarterly Progress Report
1 June 1963 to 31 August 1963

Contract Nr. DA 36-039 sc-90750

DA Project Nr. 1-G-6-20901-A-040-01

September 30, 1963

This research study deals with thin, lightweight, flush mounted, slot array antennas illuminated by a surface wave.

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LIST OF ILLUSTRATIONS

I. PURPOSE OF CONTRACT

A study of techniques to provide a shaped beam antenna of light-weight, flush configuration and reduced thickness is to be carrier out. Specifically the investigation will be devoted to the development of techniques for using the partially dielectric loaded parallel plane wave-guide, which supports surface wave propagation, to illuminate an array of slots. The array of slots will be machined in one of the side walls of the trough guide. Special attention will be devoted to efficiently launching the desired surface wave mode.

It is expected that this techniques study will follow the following sequence.

1. A study of techniques for efficiently launching a loosely bound surface wave.
2. A study of the properties of individual slots in the side wall of the trough guide
3. Investigation of procedures for synthesizing specified shaped beams
4. Construction and testing of a model that illustrates the above techniques.

II. ABSTRACT

In an effort to improve the structural properties of array plates, copper clad teflon has been investigated. Based on data from single slots and a 10 x 2 element array, this material was found to be unsuited to the desired application. Surface waves set up on the dielectric enhanced the mutual coupling between slots, making array design based on single slot data impossible.

Attempts to shorten the taper section were unsuccessful, however a possible alternative method involving the direct launching of a loosely bound wave is given.

The required amplitude and phase distributions necessary for the $\csc^2\theta$ pattern have been determined and an initial 27 x 2 element array has been constructed. A larger trough waveguide capable of supporting a 100 wavelength long array of slots is being built. This will produce the narrow E plane beam width.

III. PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

Publications:	None
Lectures:	None
Reports:	M. Cohn, R.S. Littlepage, "Investigation of Improved Airborne Antenna Techniques for Combat Surveillance," Electronic Communications, Inc., Fourth Quarterly Progress Report on Contract Nr. DA 36-039 sc-90750; June 28, 1963
Conferences:	On August 9, 1963, Mr. Stafford Thompson and Mr. John Kerr of USAELRDA visited our Laboratory to discuss progress on this contract.

IV. FACTUAL DATA

A. Copper Clad Teflon

Single slots and the first 10 x 2 element array were fabricated in .015" brass plate. For thin plates, the coupling coefficient is essentially independent of slot thickness (t) in $C_o(s, w, t, f)$. For arrays with large apertures, however, the requirement of maintaining nearly exact wall spacing (b) in the trough prohibits the use of such flexible material. With a view to the structural problems inherent in constructing and supporting a thin plate containing an array of slots, a copper clad dielectric material has been investigated. The material was glass reinforced teflon with one ounce (.003") of copper on one side (Continental Diamond Fiber Corp. grade 108TK). Dielectric thicknesses of .030" and .060" were investigated. Slots were milled in the copper region. The functional dependence of coupling coefficient with angle, $\Psi(\psi)$, and height, X(x), was reconfirmed.[1] The dependence on slot dimensions and frequency, $C_o(s, w, t, f)$, was also investigated. As one would expect, resonance at a given frequency occurred with a shorter physical length slot due to the dielectric loading. For slots of width (w) = .0508 cm, at 35 Gc, the resonant length shifted from s = .35 cm in brass to s = .325 cm in the .030" copper clad dielectric material. It was furthermore observed that at resonance (maximum coupling through the slot) the coupling coefficient of a slot in the copper clad dielectric material was less than that of a resonant slot in a thin brass plate. The coupling coefficient is a measure of the amount by which the radiated power outside of the trough is reduced from the surface wave power propagating within the trough. The measured decrease in coupling coefficient was 2.2 db in the .030" material. In the case of a resonant slot of the same width (w = .0508 cm) in the .060" thick copper clad dielectric material, the coupling coefficient was 12.2 db less than that of a resonant slot in the brass plate. In the .060" material it was found that several values

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1. These measurements were made as described in the Third Quarterly Progress Report on this contract.

of slot length (s = .3 cm, .35 cm, .425 cm) resulted in approximately the same amount of energy coupled out, this being a maximum.

A 10 x 2 element array was constructed in the .003" copper and .030" teflon material. This array was designed to have a constant amplitude illumination and the individual slot parameters are given in Figure 1 of the Fourth Quarterly Progress Report on this contract.[2] The predicted and measured patterns for the H and E planes are given in Figure 1 and Figure 2 respectively. As can be seen in Figure 1, the measured patterns are in poor agreement with regard to the depth of the nulls and magnitude of the peaks. This poor agreement along with the observed single slot phenomena seemed to indicate that a surface wave was being set up on the dielectric sheet on the outside of the trough. This would explain the unexpectedly low coupling coefficients of single slots since some of the energy coupled through the slot would be trapped on the dielectric. Also the apparent multiple resonant lengths of slots associated with the .060" dielectric could be accounted for by preferred launching conditions of the surface wave setup on the dielectric. An experiment was performed to test the validity of this surface wave model. A single slot of length s = .325 cm and width w = .0508 cm was constructed in the center of a 50 x 80 wavelength sheet of the .030" material, and was directly excited by rectangular waveguide. In the predicted pattern of the 10 x 2 element array, the element factor was that of a resonant slot. This is given in Figure 3 and it can be seen that the measured pattern of the single slot is in good agreement. Only half of the measured pattern is shown since it had good symmetry about $\theta=0$. Consider, however, that both a resonant and a non-resonant slot should have a null in the plane of the dielectric at $\theta=90^{o}$. That is, there should be no radiated energy in the plane of the dielectric and hence no edge effect at the

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2. M. Cohn and R. Littlepage, "Investigation of Improved Airborne Antenna Techniques for Combat Surveillance," Electronic Communications, Inc., Fourth Quarterly Progress Report on Contract DA-36-039 sc-90750; June 28, 1963, pp. 14.

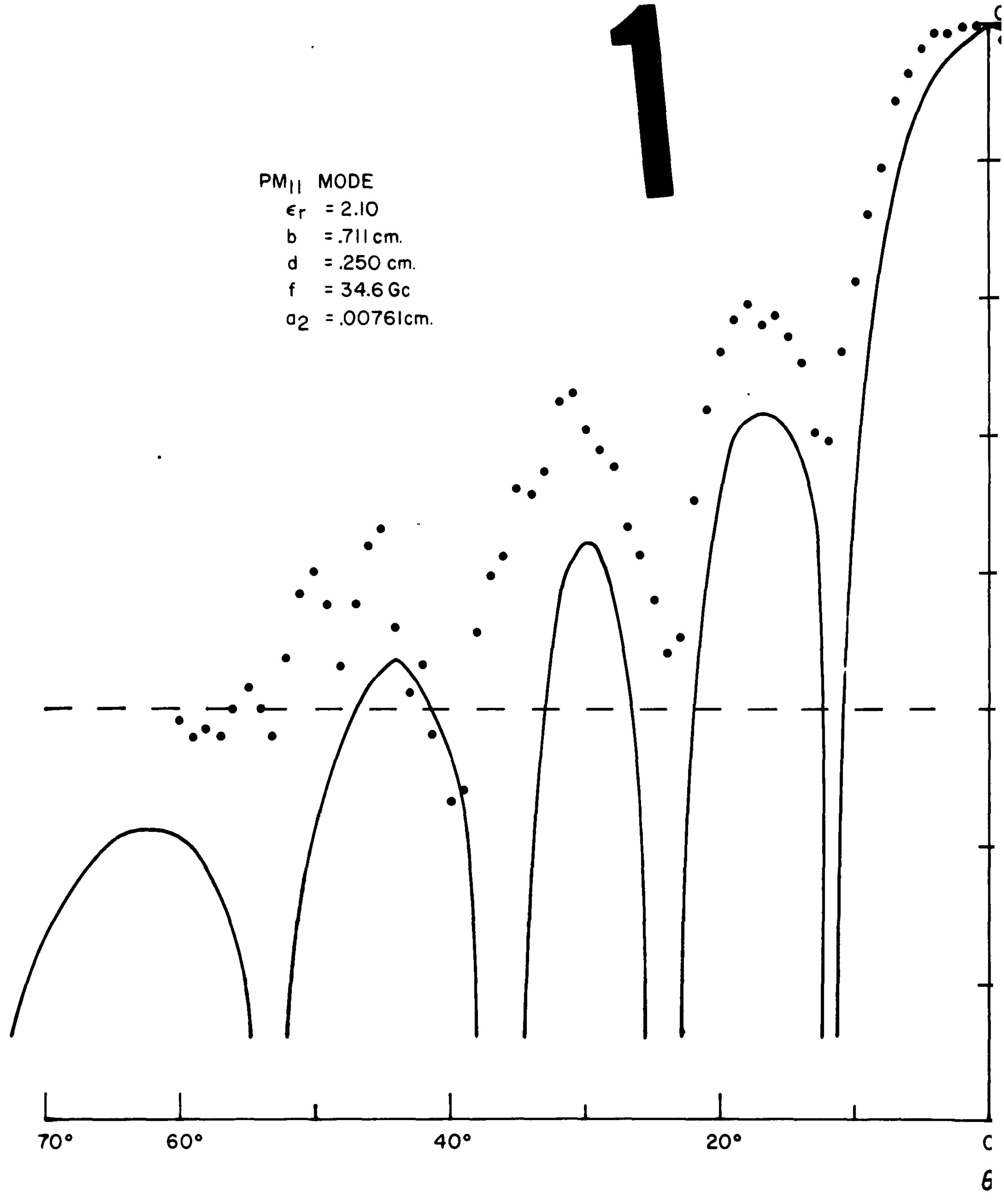
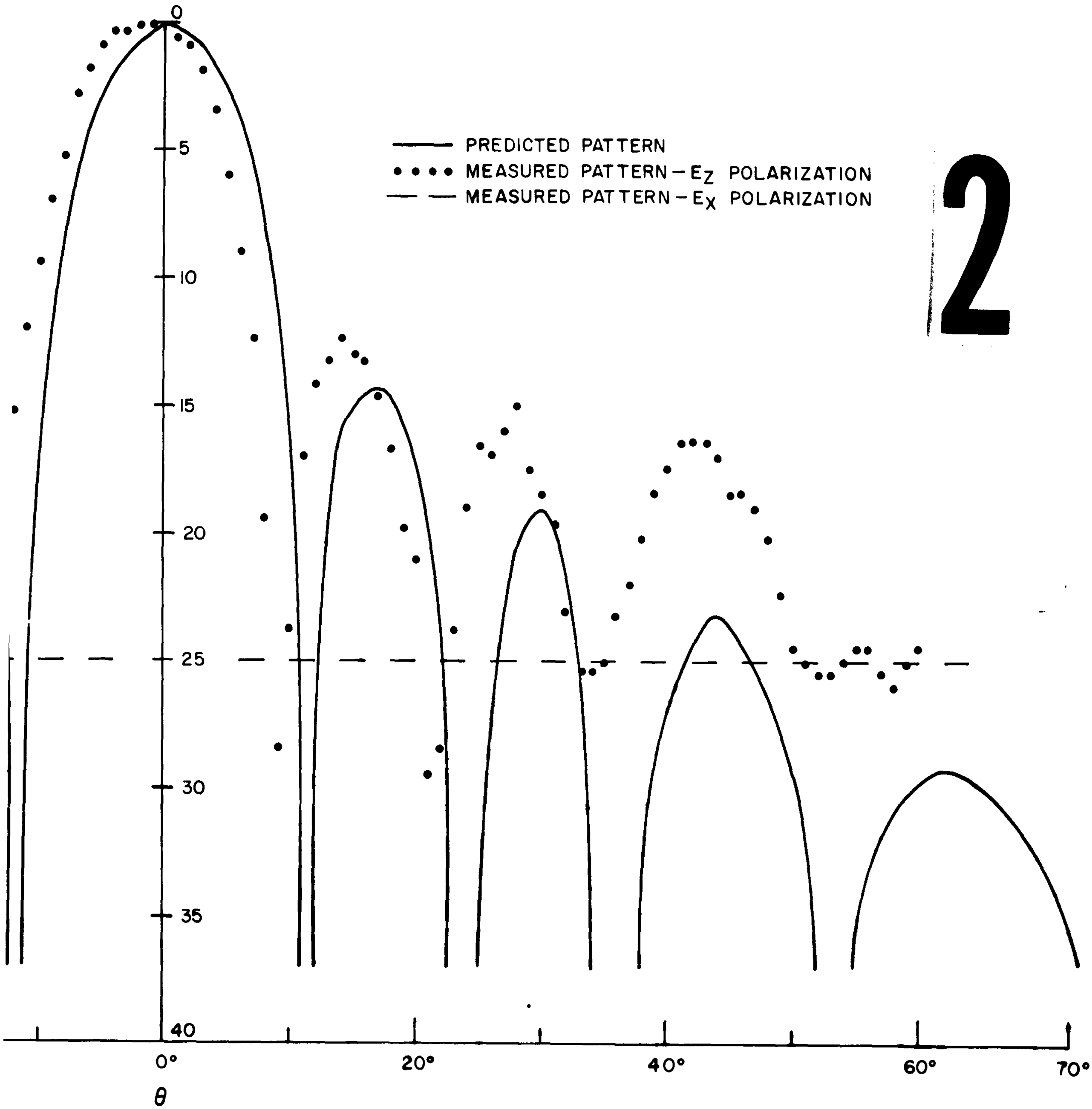


FIG. 1 —PATTERN OF THE 10 x 2 ELEMENT ARRAY IN .003" Cu WITH
H PLANE.



003" Cu WITH .030" TEFLON BACKING - CONSTANT AMPLITUDE ILLUMINATION -

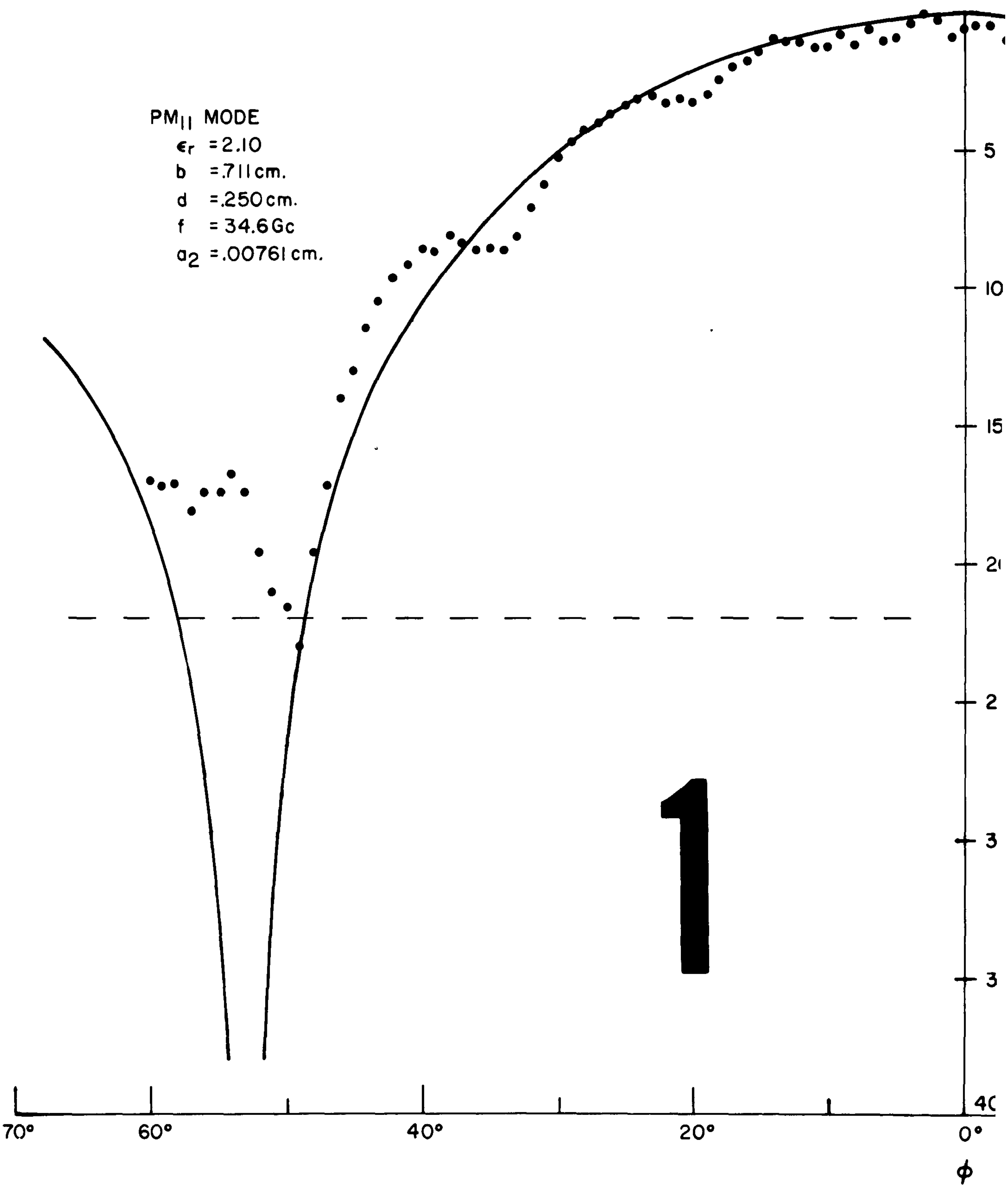
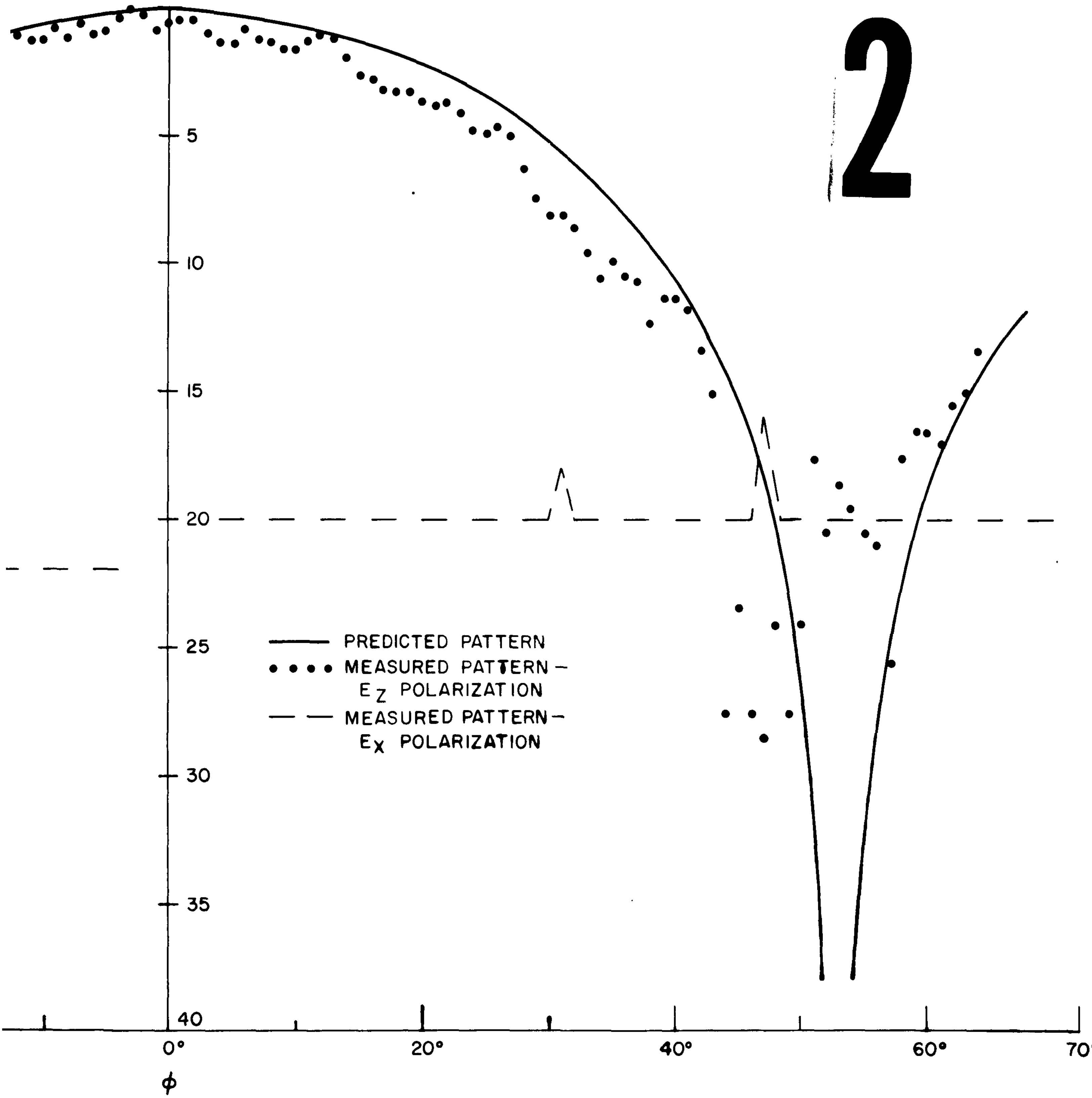


FIG. 2 – PATTERN OF THE 10 x 2 ELEMENT ARRAY IN .003" Cu WITH .03
E PLANE.

2



.003" Cu WITH .030" TEFLON BACKING - CONSTANT AMPLITUDE ILLUMINATION -

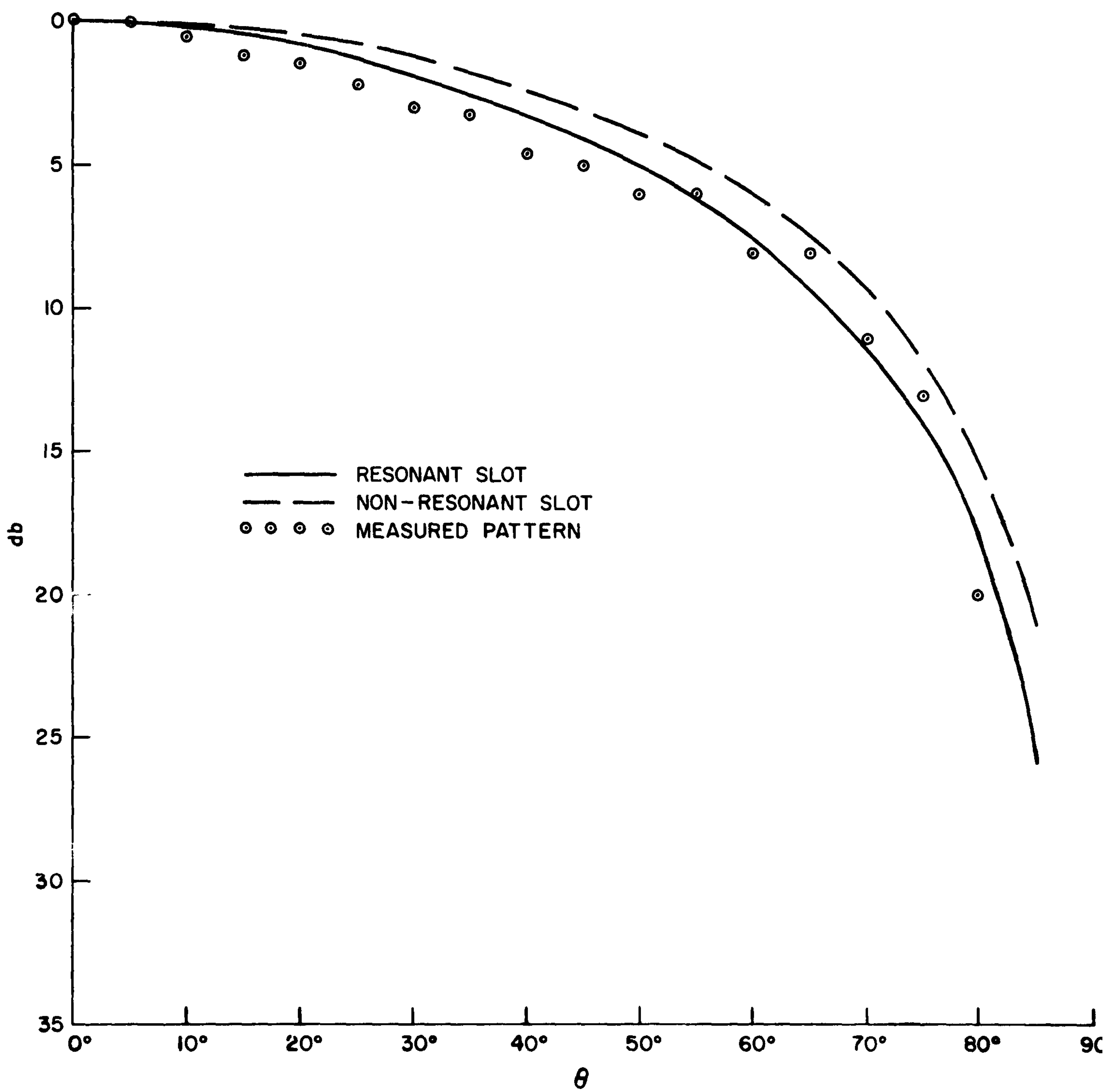


FIG. 3 —PATTERN OF A SINGLE SLOT IN A DIELECTRIC SHEET
50 x 80 WAVELENGTHS.

boundary of the large copper clad dielectric sheet. This was not found to be the case. The movement of small objects at the edge of the dielectric produced non-negligible changes in the radiation pattern, indicating that energy was propagating on the dielectric material. This is in the form of a surface wave and would be an even larger effect in thicker dielectrics since the wave would be both more efficiently launched and tightly bound. Hence, although the measured single element pattern was satisfactory, one can no longer consider each slot to be an independent radiator but must take into account energy coupled from one slot to another by some complicated surface wave mechanism. This would account for both the observed single slot data and the poor agreement in the pattern of the 10 x 2 element array. Since with every change in the relative slot positions, one would have a different mutual coupling via the generated surface wave, no simple correction exists for the single slot data. Therefore, it is felt that this copper clad, glass reinforced teflon is not suited to this application. The possibility of finding other materials, with lower dielectric constants which would result in less efficient excitation of a surface wave and hence reduced mutual coupling still exists. Further effort in this area is needed if it is deemed essential that a copper clad dielectric material be used for the convenience of etching large arrays of slots.

B. Exponential Taper Sections

As described in the Fourth Quarterly Progress Report,[2] surface waves of high purity have been achieved using approximated exponential tapers. The launching configuration described used a 28.5 cm section (ℓ_1) of .0761 cm teflon and a taper length (ℓ_2) of 19.75 cm to the desired .00761 cm thickness. This results in 48.25 cm used to achieve the required thickness (a_2) for the proper field extent necessary to illuminate a large column of slots. An effort has been made to shorten this section and hence increase antenna efficiency through the elimination of excess trough guide with its dissipative losses. As a first attempt, the straight section ℓ_1 was shortened

5 cm and the exponential taper held as before. This resulted in a decrease in field purity as determined by measuring the rate of field decay in a region where an array would be constructed. The problem of tapered sections is not readily solved by analysis and hence many experimental trials would be needed to absolutely define the optimum taper configuration. Correct combination of straight section ℓ_1 and exponential taper ℓ_2 may allow a decrease in overall length, with an increase in launching efficiency. The existing trough, however, has sufficient length to allow 48.25 cm to be devoted to launching and tapering. Since at this time it seems that only small gains in launching efficiency could be achieved in a limited program of study, the need to continue with the desired beam shaping problem will require using this length for launching the loosely bound wave.

The launching and tapering configuration shown in Figure 6 of the Fourth Quarterly Progress Report[2] was reproduced in the one meter long trough used for slot studies. Figure 4 confirms the rate of field decay in the region where the array for investigating the $\csc^2\theta$ pattern will be located. Note that the predicted rate of decay (k_2) is 1.55 db/cm since the dielectric thickness (a_2) in this region is .00635 cm.

During these taper studies, a significant decrease in launching efficiency was observed for identical taper configurations. Experiment showed that this was attributable to a marked increase in dissipative loss in the dielectric tape The present method involves laying a teflon tape using Chemiseal 201 epoxy. A uniform epoxy thickness of .0017 cm is used over the entire length In the thin region, a_2 = .00635 cm, this still represents 37% of the bulk material. Hence, its electrical properties are not negligible Removing the tape showed that the epoxy had failed to harden completely. This may have been accompanied by an increase in loss tangent. Apparently some aging process had occurred even though the epoxy is stored at low temperature as suggested. New epoxy was used with more favorable results.

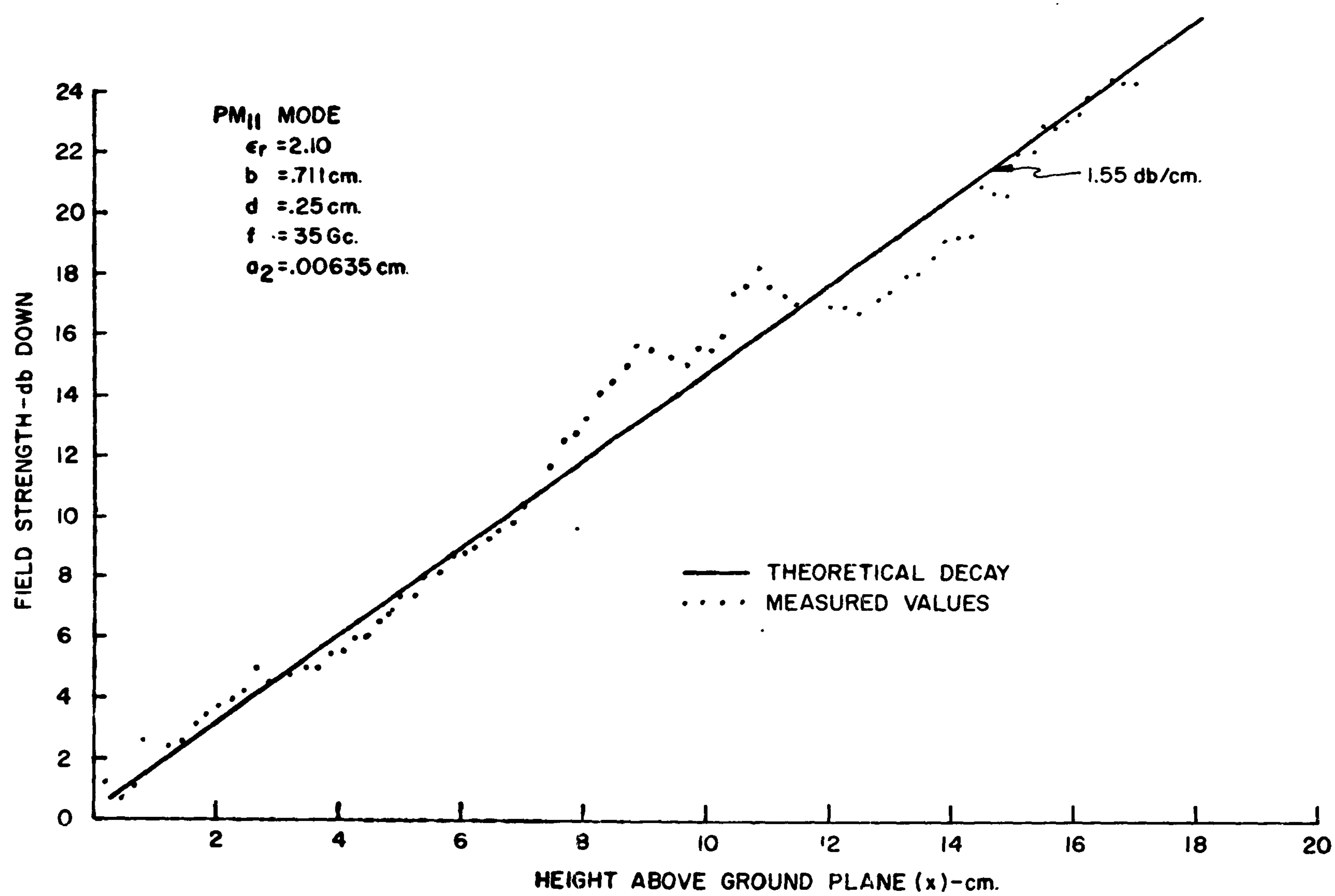


FIG. 4 - FIELD DECAY WITH HEIGHT ABOVE GROUND PLANE AT A POINT 88 cm. FROM LAUNCHING SLOT.

This exemplifies a problem which is of great interest to future trough technology The very presence of an epoxy limits the minimum thicknesses which can be achieved, and hence the transverse wave number which determines the height to which arrays of slots can be extended. This also puts an upper limit on frequency in trough guide structures. For these reasons and also in view of machining problems involved in the present method, interest has been generated in various deposition techniques which allow the dielectric to be directly deposited on the ground plane. Correspondence with several firms indicates that the present state of the art would allow the depositing of very thin films (1 micron) on reasonably long ground planes with a satisfactory tolerance on thickness (5%). In the present application a thicker film would be deposited and the required taper section milled out.

For some time there has been interest in both improving launching efficiency and doing away with the taper section. The logical approach would be to replace the single launching slot, the magnetic line source, by some configuration of slots which would directly approximate the desired loosely bound wave In this arrangement one would launch directly onto the desired thin tape Hence the deposition technique would be used to its fullest advantage. The desired exponentially decaying field would be approximated by a series of slots in one of the end plates of the trough. The principle problem has been in exciting the slots in phase. In a conference with Mr. Stafford Thompson and Mr. John Kerr of USAELRDA it was suggested that an approach might be to excite the trough via a group of slots cut in a conducting wall located at the z=0 plane of the trough. These slots would in turn be energized from a rectangular waveguide placed so that one of its broad walls lies on the z=0 plane. All of the slots would be energized in phase if they were spaced at intervals of one waveguide wavelength of the rectangular waveguide. Some development will be needed to determine the proper slot widths required to simulate the exponential amplitude decay. This slotted waveguide would serve as one end of the trough guide and launch the loosely bound wave directly into the trough. This method could result in a twofold gain by increasing launching efficiency and hence field purity and decreasing the length of trough necessary for a given antenna application. If time permits, this method will be investigated during delays in the regular program.

C. Csc$^2\theta$ Radiation Pattern

The method used to synthesize the desired csc$^2\theta$ radiation pattern was that described by Woodward.[3] Each slot acts as a source, of finite size, of a plane wave. The array of slots taken together result in a continuous spectrum of plane waves each independently having the characteristic $\frac{\sin^2 x}{x^2}$ radiation pattern. By adjusting the amplitude and phase of each slot, a Fourier summation of the individual patterns will result in the desired csc$^2\theta$ pattern. It was found that an excellent approximation of the csc$^2\theta$ pattern could be achieved with an aperture of 15λ. An analysis was performed to determine the necessary amplitude and phase distribution and the results appear in Figure 5 and Figure 6. Since radiating elements, the slots, are located at half wavelength spacings, an array with $n\lambda$ aperture would contain $2n+1$ slots. Hence a 15λ array should contain 31 slots in a column. It can be seen, however, in Figure 5 that the slots in positions $x/\lambda = \pm 7.5$ and ± 6.5 would couple very little energy and therefore can be omitted. This thinning results in an array having the same radiation pattern with an aperture of 14λ and 27 slots in a column.

In order to verify the csc$^2\theta$ radiation pattern in the H plane, an array of 27 x 2 elements has been designed and built. The design

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3. P. M. Woodward, "A Method of Calculating the Field Over a Plane Aperture Required to Produce a Given Polar Diagram," Journal of the Institute of Electrical Engineers, 93, Part III A, pp. 1554-1558; 1947.

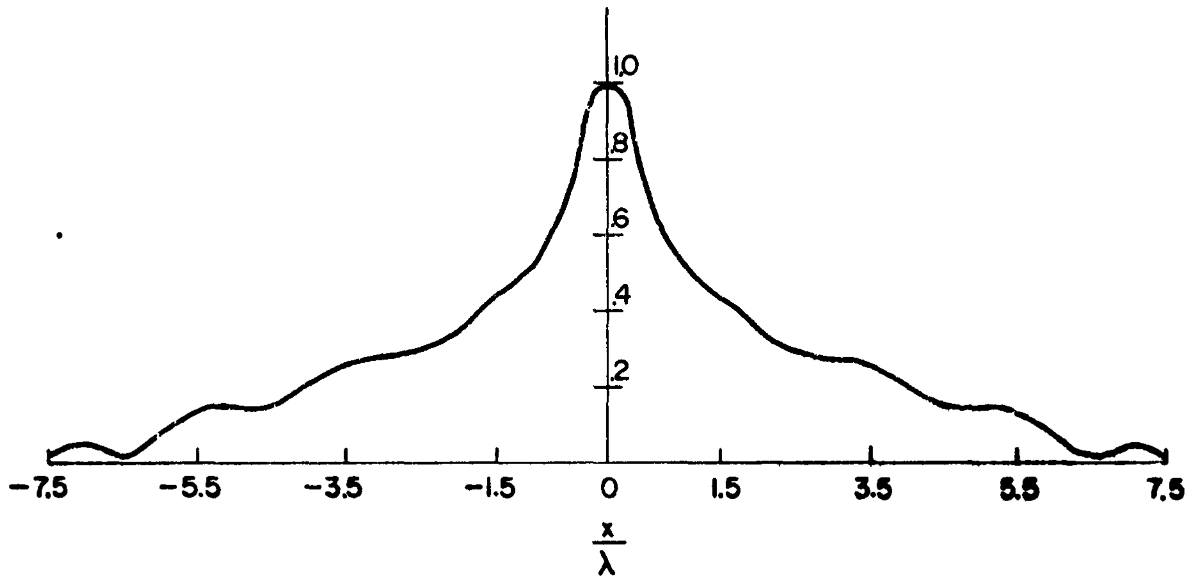


FIG. 5 –AMPLITUDE DISTRIBUTION OVER 15 λ APERTURE

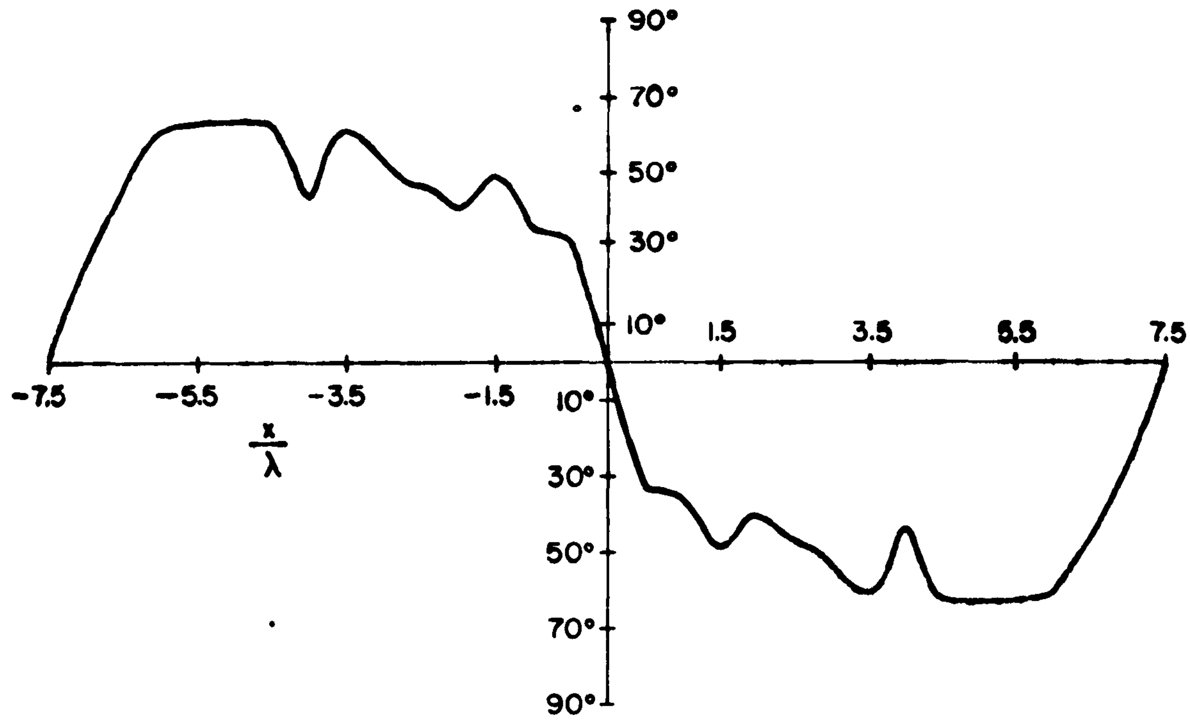
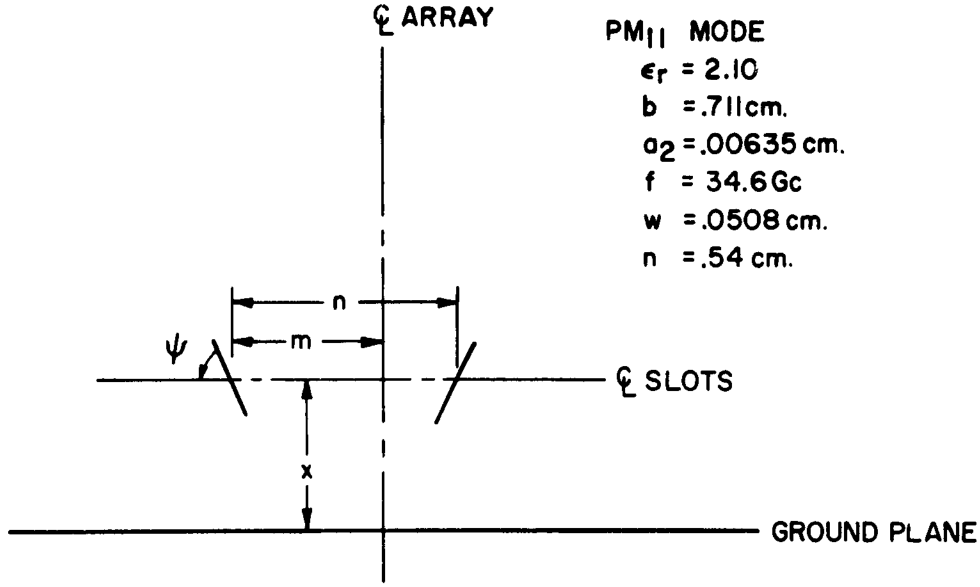


FIG. 6 –PHASE DISTRIBUTION OVER 15 λ APERTURE

data is given in Figure 7 and a picture of the completed array in Figure 8. The slots are all the same width, w = .0508 cm, but in order to achieve the desired range of coupling coefficients it was necessary to vary the slot length (s) and angle (ψ) with the ground plane. The material used was .030" brass plate. This initial array is designed for use in the existing one meter long trough. Patterns will be measured on the outdoor range, working well beyond the required two Rayleigh distances to insure far field patterns. This requires the increased sensitivity of a superheterodyne receiver. The local oscillator klystron will be adjusted to give an intermediate frequency of 120 Mc. Mixing will be accomplished in a 1N53 crystal in an FXR-U206B detector mount. A block diagram of the proposed system is given in Figure 9. The system has been bench operated with a sensitivity in the -100 dbm range.

While these initial pattern measurements are being made, a larger trough guide is being constructed which will be capable of mounting arrays up to apertures of 100λ in the E plane. This would result in a theoretical beam width of a half of degree.



Slots numbered 1 thru 27 from the ground plane

Slot #	s (cm)	x(cm)	m(cm)	ψ
1	.20	.25	.351	85°
2	.20	1.116	.453	82.5°
3	.20	1.549	.460	74.5°
4	.30	1.982	.460	86.7°
5	.30	2.415	.460	86.5°
6	.40	2.848	.403	87°
7	.40	3.281	.460	86.1°
8	.40	3.714	.428	85.6°
9	.40	4.147	.411	85.2°
10	.40	4.580	.390	84°
11	.40	5.013	.417	82.4°
12	.40	5.446	.375	80.5°
13	.40	5.879	.371	75°
14	.40	6.312	.270	65°
15	.40	6.745	.169	72.2°
16	.40	7.178	.165	76.2°
17	.40	7.611	.123	77.5°
18	.40	8.044	.150	79°
19	.40	8.477	.129	80.4°
20	.40	8.910	.112	80.4°
21	.40	9.343	.080	80.2°
22	.40	9.776	.137	82°
23	.40	10.209	.080	83°
24	.40	10.642	.080	82.6°
25	.40	11.075	.080	82.7°
26	.40	11.508	.087	85.4°
27	.40	12.374	.189	86°

FIG. 7 – 27 x 2 ELEMENT ARRAY – $Csc^2\,\theta$ RADIATION PATTERN

Figure 8 - 27 x 2 Element Array for $\csc^2\theta$ H-Plane Radiation Pattern

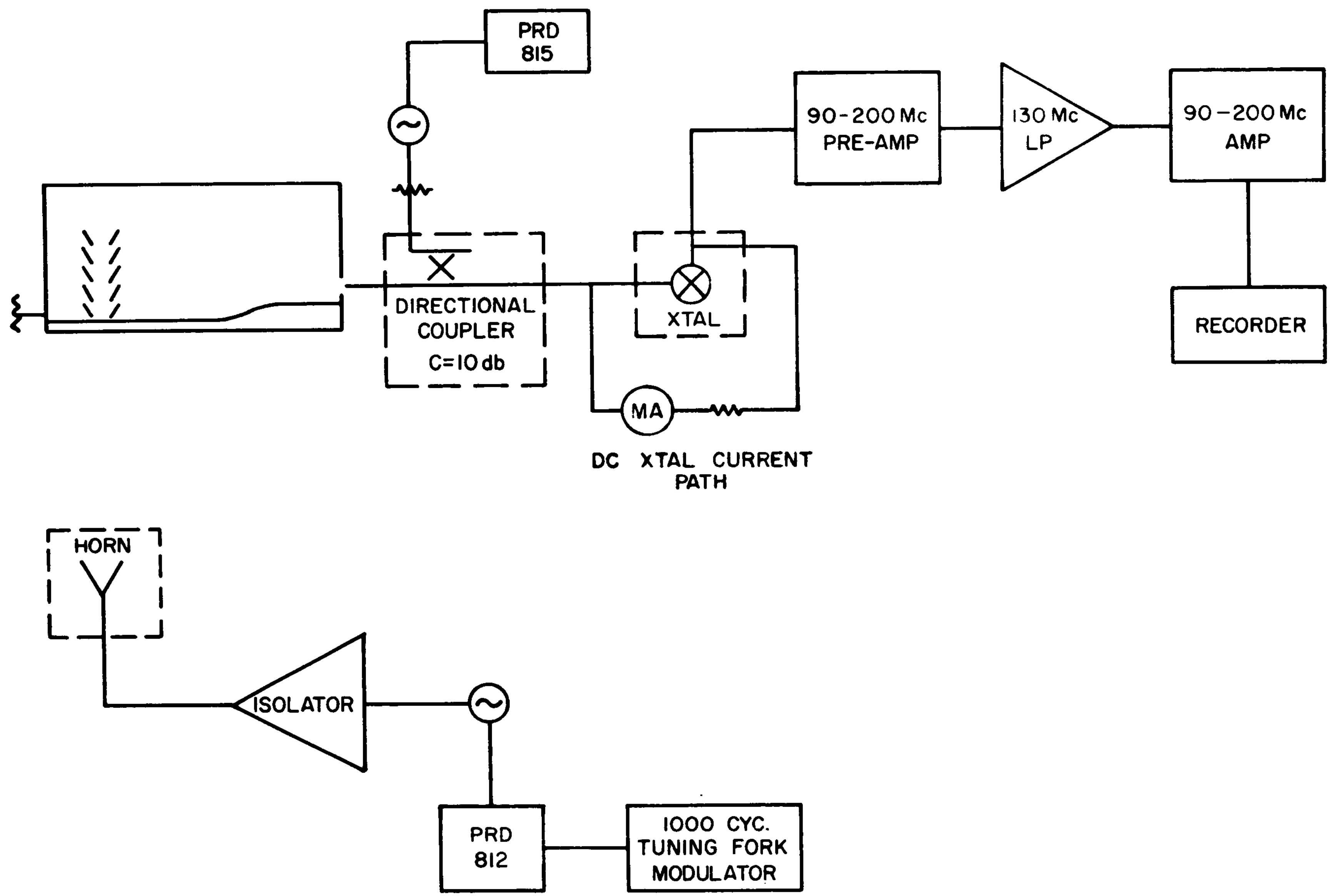


FIG. 9 —BLOCK DIAGRAM OF PROPOSED PATTERN RANGE EQUIPMENT LAYOUT

V. CONCLUSIONS

Copper clad teflon glass material was investigated as a possible substitute for thin brass array plates. Two samples were tested, both having .003" copper and with dielectric thicknesses of .030" and .060". Experiments on both single slots and a 10 x 2 element array indicate that a surface wave has been set up on the dielectric. This enhances mutual coupling, making the radiation pattern of an array of slots impossible to predict based on single slot data. For this reason it is felt that the described material is not suited for this application. It is possible that these mutual coupling effects can be somewhat reduced through the use of a lower dielectric constant material on which the undesired surface wave would be both more loosely bound and less efficiently excited.

Attempts to shorten the straight section (ℓ_1) prior to the exponential taper section (ℓ_2) resulted in a decrease in launching efficiency and purity of the loosely bound surface wave. Since space is not a limitation in the existing trough guide, the original taper configuration requiring 48.25 cm will be used in array pattern measurements. Using this taper, launching efficiency has been measured as 63% and probing has verified surface wave purity to heights of 18 cm. A possible method for efficiently launching a loosely bound wave directly on a thin dielectric, thus eliminating taper sections, is described. Success in this area would result in increasing both antenna efficiency and the upper frequency limit of trough type structures.

The first $\csc^2\theta$ array plate has been designed and built. The array consists of 27 x 2 slots, giving an H plane aperture of 14λ. A superheterodyne system has been tested and found to give sufficient dynamic range for good pattern measurements at ranges well in excess of two Rayleigh distances. Once the $\csc^2\theta$ pattern has been verified, a larger array having the desired narrow E plane beam width will be designed. A larger trough guide capable of mounting an array with an E plane aperture of 100λ is being built.

VI. PROGRAM FOR THE NEXT INTERVAL

The E plane and H plane radiation patterns of the 27 x 2 element $\csc^2 \theta$ array will be measured for both polarizations. Examination of these results will determine if this 54 slot subarray is a satisfactory element for the desired larger array. Based on this unit, a large aperture array will be designed having the necessary E-plane amplitude distribution required for the desired narrow beamwidth. With a view of manufacturing problems involved in our array of many slots and a possibility of increasing bandwidth by decreasing the number of columns, thinning techniques in the E-plane will be investigated for this large array.

In order to determine the gain in launching efficiency that might be obtained using a multiple slot launching technique, an analysis will be performed. If the requirements on the number of slots and range of coupling coefficients involved for a substantial increase in launching efficiency looks favorable, experimental verification will be obtained with a view to incorporation in the trough guide antenna. This would make launching directly onto thin dielectrics possible and deposition techniques would be further investigated.

VII. PERSONNEL

Marvin Cohn - Manager, Microwave Section - 106 hours

Received B.S.E.E. in 1950 and M.S.E.E. in 1953 from the Ill. Inst. of Tech., Chicago, Ill. Received Dr. Eng. degree in 1960 from the Johns Hopkins Univ. Electronics engineer with the Martin Co., Baltimore, Md.: 1952-1952. Member of the staff of Radiation Laboratory of Johns Hopkins University from 1952 to 1960 except for a two year leave of absence spent in the U.S. Army Signal Corps. Stationed at While Sands Proving Ground, New Mexico; 1953-1955. Joined Research Div. of ECI 1960; appointed Research Manager, Microwave Section, 1963.

Robert S. Littlepage - Junior Engineer - 464-1/2 hours

Employed by the Martin Co., Baltimore, Md., prior to entering college. He worked with ultrasonics and X-rays applied to non-destructive testing. From 1958 to 1962 he attended Loyola College in Baltimore, receiving B.S. degree in Physics. While an undergraduate he was a student supervisor on a project performed for the Ballistic Research Laboratory of Aberdeen Proving Ground. Mr. Littlepage joined the Research Div. of ECI in June 1962. He is currently doing graduate work in Physics at the Johns Hopkins University.

Kenneth E. Hare - Senior Instrument Maker - 462 hours

Marvin Hoster - Instrument Maker - 119 hours

William Jung - Instrument Shop Supervisor - 42 hours

Other personnel contributed a total of 75 hours during this quarterly reporting period. They are listed below:

Dr. James C. Wiltse - Research Manager, Microwave Section

William C. Yaeger - Junior Draftsman

Paul W. Hayes - Electronic Technician

Robert Hanna - Senior Draftsman

Charles Zellhofer - Senior Electronics Technician

Thomas Kehoe - Senior Electronics Technician

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Contract No. DA 36-039 sc-90750
DA Project No. 3A99-23-001

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Unclassified
1. Antenna
2. Wave Propagation
3. Microwave Circuits

AD______________ ACCESSION NO.______________

Electronic Communications, Inc., Research Division
1830 York Road, Timonium Md.
Investigations of Improved Airborne Antenna Technique for Combat Surveillance - Report No 5 - Sept 30, 1963
21 pp 9 illus 0 tables
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